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[EFFICIENCY OF CENTRIFUGAL PUMP]

CALVERT & CLUDIUS

Efficiency of Centrifugal Pump.

by

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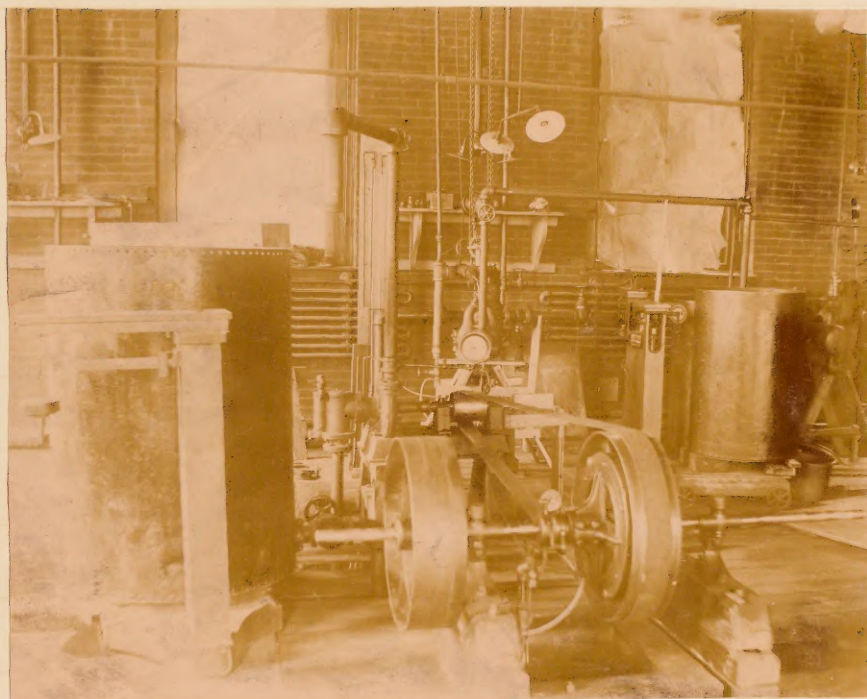
May 13 1897.



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Efficiency of a Centrifugal Pump.

The object of the tests made was to find the efficiency of a centrifugal pump number 1½ made by Ervin & Van Wie of Syracuse, New York, at different heads and speeds.

The efficiency is the ratio of the power derived from the pump, measured by the product of the weight of the water into the distance through which it is raised, to the power supplied to the driving pulley on the counter-shaft as measured by an Emerson power scale.

The power for running the

pump was obtained from a main shaft driven by a high speed Westinghouse engine.

It was then conveyed by a $3\frac{1}{2}$ inch belt to pulley E on the counter-shaft which was supported from the floor. From pulley F near the other end of this shaft, another $3\frac{1}{2}$ inch belt transmitted the power to pulley G which was fastened to the axle of the pump A.

The speed of the pump was varied by changing the pulleys on the main and counter-shafts.

The water to supply the pump was obtained from a large tank, located beneath the floor, by means of a pipe $2\frac{1}{2}$ inches in diameter, marked K, having a

foot valve at the end. From the pump the water was discharged through a $2\frac{1}{2}$ inch pipe, L, into a large iron tank, B, placed upon a pair of Fairbank's standard scales, C. The valve M in the discharge pipe L (located above the pressure gauge) was used to throttle the water and in this way increase the pressure head on the pump. The pressure gauge J was placed in communication with L to measure this pressure head. When the tank B was full the water was discharged (by shifting L) into a box N connected to a pipe O which conducted the water back into the tank below the floor.

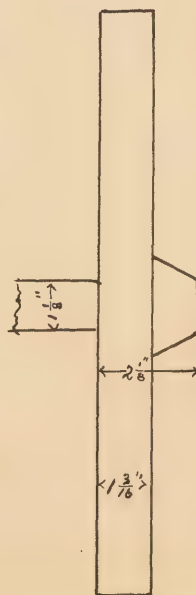
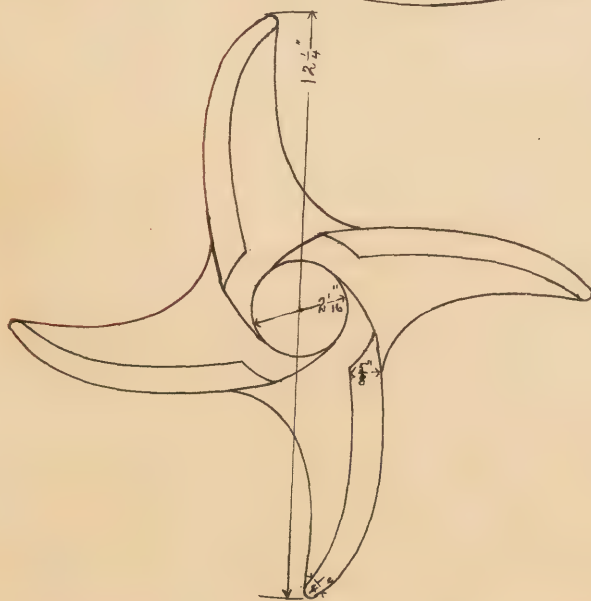
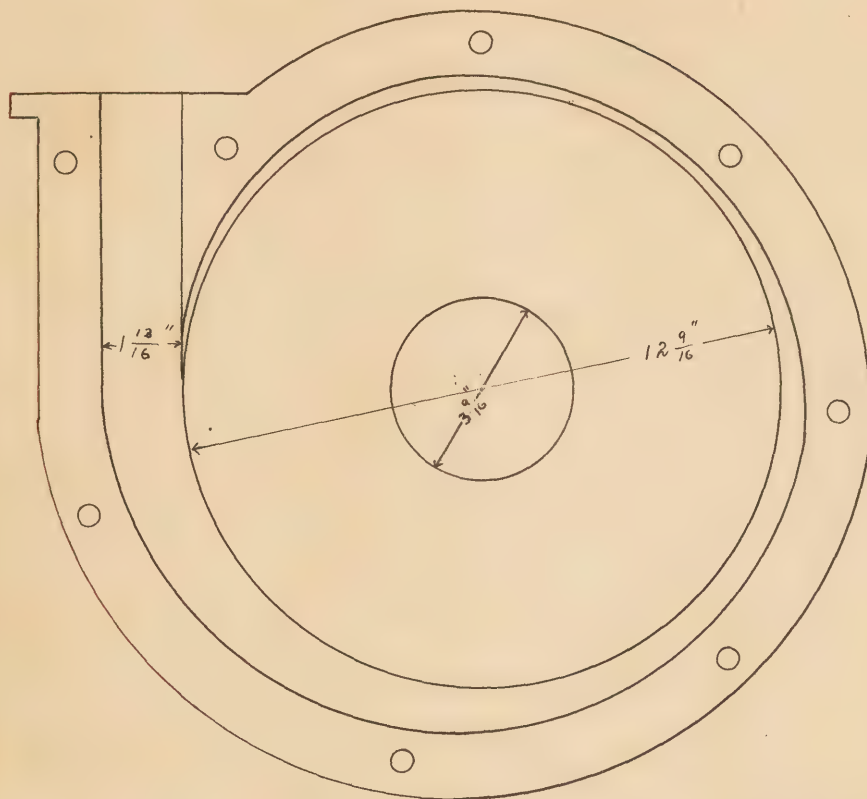
The speed of the pump was measured by a counter, H, attached to the end of the pump axle. This counter registered every ten revolutions. The Emerson power scale was fastened to the counter-shaft and made to drive pulley F which was loose. The number of revolutions per minute of the counter-shaft was obtained by a speed-counter attached to the dynamometer. This registered every revolution. The driving force was observed as usual on the quadrant scale. D.

The casing of the pump consists of two circular dished castings bolted together around the circumference with a rubber

gasket intervening to make an air tight joint. One of these castings has a long thrust bearing with a stuffing box attached to the end of it. This is for the shaft to which the rane is attached, the box acting to keep the water from leaking around the shaft.

The other casting has the inflow pipe with the hand pump attached to it. The object of the latter is to fill the main pump before starting. The edge of the hole where the water enters was rounded off so as to give the water freer access to the pump. On the next page is given a view of the inside of the pump and of the

Inside of pump. scale 3"=1'



7.
vanes which revolve between the outside casings. The vanes consist of an iron casting having four curved arms which revolve so that the convey side leads.

This throws the water tangentially off them into the spiral groove extending around their ends and so out of the pump in a vertical direction. The clearance between the flat surface of the vanes and the outside casing was $\frac{1}{32}$ of an inch. As it is essential in this style of pump that no air be left inside, a small petcock is inserted in the top of the casing so that any air that has accumulated may be allowed to escape. In starting the pump

the cock is opened until all the air is forced out.

Methods of Calibrating Instruments.

The pressure gauge was calibrated by means of a Crosby's gauge tester in the usual way.

The vacuum gauge was compared with a mercury manometer by attaching both to a pipe in communication with the steam side of a surface condenser. Exhaust steam was admitted the condensation of which within the closed vessel created a vacuum which was registered on the manometer and

gauge. The vacuum was increased to the limit of the manometer readings being taken at approximately every pound increase. Air was then gradually admitted and readings again taken as the vacuum was reduced. These results are given in Table IV.

To calibrate the Emerson power scale a Prony brake was made consisting of a framework of $\frac{1}{2}$ inch iron pipe. The belt being removed from pulley F, a rope was passed around it and fastened to this frame. The knife edge at the other end of the frame rested upon a pair of Fairbank's scales. The rope being loose on the pulley, the

10.
counter shaft was turned by hand in the direction it ordinarily ran the weight on the scales being noted. This was equal to the weight of the brake plus the friction of the rope. The shaft was then rotated in the opposite direction when the apparent weight was equal to the friction minus the brake weight. Subtracting the latter from the former and dividing by two gives the weight of the brake alone. This was subtracted from the weights corresponding to the deflections on the dynamometer scale. By varying the tension on the rope and reading the weight on the scales, the horse-power correspond

ing to that deflection of the power scale was calculated according to the formula

$$HP = \frac{2\pi W \cdot a \cdot n}{33000}$$

where W = weight on scales minus the weight of hake.

a = perpendicular distance between the knife edge and center of the shaft

n = number of revolutions

This horse power is also equal to $\frac{K \times D \times n}{33000}$

where K = the constant of the dynamometer

D = the deflection of arm
 n = number of revolutions of shaft.

Hence $K = \frac{2\pi W a}{D}$

These results are given in Table V. A curve was then

drawn with the values of K as ordinates and values of D as abscissae. From this curve the constant for any required deflection was obtained.

Methods of Conducting the Tests.

In the first test to measure the water discharged a $1\frac{1}{2}$ inch Worthington meter was placed in pipe L between M and the outflow. This was calibrated by weighing the quantity of water running through the meter in 4 minutes. At a given time the test was started by noting the meter reading. The water was then allowed to

flow into tank B until it was full, the meter was again read and the pipe L was moved so that the water flowed into the waste pipe O. The weight of the tank full and empty being known the difference gives the weight of water corresponding to difference of meter-readings in cubic feet. The speed of the pump and of the power scale, the deflection of the dynamometer, and the pressure and vacuum gauges were observed. The tank B was then emptied by means of a discharge pipe extending from the bottom down into the main tank below the floor. This series of operations was then repeated.

The quantity of water, however, was too large for the capacity of the meter, so that at the end of the first test it was taken out. Suction in pipe K was measured by a mercury manometer the difference of heights in the two tubes being measured to tenths of an inch. A vacuum gauge was substituted for this in all the following tests. The distance between the centers of the pipes leading to the pressure and vacuum gauges was 1.71 feet.

In the second test the discharge box N was not used, all the water being weighed in tank B and three smaller auxiliary ones. These were placed in a row

and when B was full the water was sent through a 3 inch horizontal pipe into the first of the smaller tanks. When this was full (its capacity was less than half that of B) the pipe was shifted to the second and then to the third. During this time B was weighed and emptied and when the third small tank was filled, B was again used and the three small tanks, each of which rested upon a pair of scales, were weighed and emptied.

The other readings were taken as in the first test, except that the two speeds and the dynamometer deflection were observed only at the commencement of the test,

no time being available during its progress.

In the third and all the following tests the waste box N was again used. The tank B was weighed empty and at a given time the water was pumped into it and when full, time was again observed and the pipe L shifted so that the water flowed into the box. The tank was then weighed and emptied and the pump speed taken. While it was filling the dynamometer deflection and speed and the two gauges were observed.

Three tests were made with each set of pulleys at different heads. These were followed by a so-called final test in which

the valve M was entirely closed.
All the readings were observed
except, of course, the weight of
water as none was being pumped.
Hence the efficiency in these cases
was zero.

Lettered Photograph

Lettered Photograph



Table I.

Calibration of Pressure Gauge

No 217760.

March 22nd '97.

1	2	3	4
Actual pressure	Gauge up	Gauge down	Gauge average
0	4	4	4
5	9	9	9
10	13 $\frac{3}{4}$	13 $\frac{3}{4}$	13 $\frac{3}{4}$
15	18 $\frac{1}{2}$	18 $\frac{1}{2}$	18 $\frac{1}{2}$
20	23 $\frac{1}{4}$	23	23 $\frac{1}{8}$
25	28	28	28

Column 1 = actual pressure on gauge.

" 2 = reading of gauge as pressure increases.

" 3 = reading of gauge as pressure decreases.

" 4 = mean of cols. 2 and 3.

Table II.

Calibration of Pressure Gauge
No

April 17th 1897.

1	2	3	4
Actual pressure	Gauge up	Gauge down	Gauge average
0	4	4	4
5	9 $\frac{1}{4}$	9 $\frac{3}{4}$	9 $\frac{1}{2}$
10	15 $\frac{1}{4}$	14 $\frac{3}{4}$	15
15	19 $\frac{1}{4}$	19 $\frac{1}{2}$	19 $\frac{3}{8}$
20	24 $\frac{1}{4}$	24 $\frac{1}{2}$	24 $\frac{3}{8}$
25	29	29	29
30	33 $\frac{1}{2}$	33 $\frac{1}{2}$	33 $\frac{1}{2}$
35	38 $\frac{1}{2}$	38 $\frac{1}{2}$	38 $\frac{1}{2}$
40	43 $\frac{1}{4}$	43 $\frac{1}{2}$	43 $\frac{3}{8}$
45	47	48	47 $\frac{1}{2}$
50	53	53	53
55	58	58	58

Table III.

Calibration of Pressure Gauge

April 27th 1897.

1 Actual pressure	2 Gauge up	3 Gauge down	4 Gauge average
0	6 1/2	6 1/2	6 1/2
5	11	12	11 1/2
10	15	16	15 1/2
15	20	20 3/4	20 3/8
20	25	25 1/4	25 1/8
25	29 3/4	30	29 7/8
30	34 1/2	34 3/4	34 5/8
35	39 1/2	39 1/2	39 1/2
40	44 1/4	44 1/2	44 3/8
45	49	49 1/4	49 1/8
50	54	54	54
55	59	59	59
60	64	64 1/4	64 1/8

Table IV.

Calibration of Vacuum Gauge
No. 203807.

April 17th 1897.

1	2	3	4	5	6
Gauge up	Manom- eter	Gauge down	Manom- eter	Man. mean.	Gauge corrected
lbs.	inches.	lb.	inches.	inches.	lbs.
3	4 $\frac{1}{2}$	3	4 $\frac{1}{4}$	4 $\frac{3}{8}$	2.147
4	6 $\frac{5}{8}$	4	5 $\frac{7}{8}$	6 $\frac{1}{4}$	3.068
5 $\frac{1}{4}$	8 $\frac{7}{8}$	5 $\frac{1}{4}$	8 $\frac{5}{8}$	8 $\frac{3}{4}$	4.295
6	10 $\frac{5}{16}$				5.369
7	12 $\frac{1}{2}$	7	12	12 $\frac{1}{4}$	6.012
7 $\frac{3}{4}$	14 $\frac{5}{16}$				6.839
8	14 $\frac{5}{8}$	8	13 $\frac{7}{8}$	14 $\frac{1}{4}$	6.994
10	18 $\frac{5}{8}$				9.162
10 $\frac{5}{8}$	19 $\frac{3}{8}$				9.755

Table IV.

- Column 1 = reading of gauge as vacuum increases.
- " 2 = difference of levels of mercury in tubes of manometer as vacuum increases.
- " 3 = reading of gauge as vacuum decreases.
- " 4 = difference of levels of mercury as vacuum decreases.
- " 5 = mean of cols. 2 and 4.
- " 6 = col. 5 $\times$.4908 which gives corrected reading of gauge in pounds.

Table V.
Calibration of Emerson Power Scale.

1	2	3	4. April 16 th 1897.
Weight	Dyn. deflection	Weight	Dyn. deflection
19 $\frac{1}{4}$	18	28 $\frac{1}{4}$	72
18 $\frac{7}{8}$	18	29	81
20 $\frac{1}{2}$	25	29 $\frac{1}{2}$	84
21 $\frac{3}{4}$	30	30 $\frac{5}{8}$	85
22 $\frac{1}{2}$	39	30 $\frac{1}{2}$	86
22	41	30	86
22 $\frac{5}{8}$	42	31 $\frac{3}{4}$	95
23	45	32	95
23	46	31 $\frac{1}{2}$	96
24 $\frac{7}{8}$	50	32 $\frac{1}{4}$	96
24 $\frac{1}{2}$	54	34	104
24	54	35 $\frac{3}{4}$	107
25	55	34 $\frac{1}{8}$	111
26 $\frac{1}{8}$	59	35	113
25 $\frac{1}{4}$	60	36 $\frac{1}{8}$	114
25 $\frac{5}{8}$	62	37	114
27 $\frac{3}{8}$	67	38 $\frac{3}{4}$	117
27 $\frac{7}{8}$	70	41 $\frac{1}{4}$	120

Table V.

Column 1 and 3 = gross weight on scales.

" 2 and 4 = deflection on dynamometer scale.

Length of brake arm = 47.01 inches.

Weight on the scales when the pulley was turned in the direction as driven by the belt was 14 pounds. When turned in the opposite direction the weight was $6\frac{1}{2}$ pounds. Hence weight of brake = $10\frac{1}{4}$ pounds.

Fold Out

Test no. 1

March 20 1897

1	2	3	4	5	6	7	8	9	10
Ht of tank empty in lbs.	Ht of tank full in lbs.	Net wt. of water in lbs.	Meter start cu. ft.	Meter end cu. ft.	Net cu. ft.	Speed of dyn. per min.	Wyn. scale	Constant for dyn.	Speed of Pump.
685.5	2140.5	1455.0	12995.7	129973.7	22.0	184	19	13.82	884865
677.5	2134.0	1456.5	139047.5	139068.6	21.1	183	19	13.82	872350
673.5	2091.0	1417.5	130164.4	130185.6	21.2	183	20	13.34	857065
662.5	2138.0	1475.5	130234.3	130255.8	21.5	185	19	13.82	847335
656.5	2155.0	1498.5	130312.8	130334.5	21.7	187	19	13.82	835770
670.5	2172.0	1501.5	130450.3	130472.4	22.1	189	19	13.82	818555
658.5	2152.0	1494.5	130569.3	130591.2	21.9	187	19	13.82	804260
			130601.4						803530

Test no. 1

11	12	13	14	15	16	17	18
Revs per min	Pres. gauge in lbs	Pres. gauge corrected	Vacuum gauge in inches	Vacuum gauge in lbs.	Total head	Pounds of water pumped	Pounds given to pump
705	13	12.4	4.7	2.307	35.59	66.138	1.233
705	13	12.4	4.8	2.356	35.70	69.028	1.226
715	13	12.4	4.8	2.356	35.70	68.420	1.258
725	13	12.4	4.8	2.356	35.70	68.627	1.239
730	13	12.4	4.8	2.356	35.70	69.056	1.256
740	13	12.4	4.8	2.356	35.70	67.940	1.267
730	13	12.4	4.8	2.356	35.70	66.690	1.256
723					35.68	67.985	1.247
							Means

Test no. 1

Time of beginning test 11 hrs. 25 min 0 sec

" " End of " 1 hr 25 min 0 sec

Duration of test 2 hours.

Total no. cu. ft. $130601.4 - 129951.7 = 649.7$

" " of lbs. $649.7 \times 67.985 = 44170$

67.985 mean of column 17

Column 3 = col. 1 - col. 2

" 6 = " 5 - " 4

" 9 obtained from curve.

" 11 = differences of column 10.

" 13 from table I

" 15 = col. 14 $\times$.4908 which changes it from inches to pounds.

column 16 = column (13 + 14) $\times$ 2.304

which gives feet of lift to which must be added distance between pressure and vacuum gauge, which is 1.71 feet.

column 17 is number of pounds

Test 1

of water that pass through
the meter when it registers 1 cu ft.
column 18 is dynamometer reading
times dyn. constant times dyn.

speed divided by 33000, which
is equal to $\frac{\text{col. 8} \times \text{col. 9} \times \text{col. 7}}{33000}$

$$\text{Power of pump} = \frac{44170 \times 35.68}{120 \times 33000} = .396$$

which is number of lbs of water times
total head from col. 16 and divided
time and 33000 to change it to
horse power.

$$\text{efficiency} = \frac{.3960}{1.247} = 30.9 \%$$

Test no. 2.

April 10th 1897

1	2	3	4	5	6	7	8	9	10
Lbs of blank full	Lbs of blank emp.	Net	Lbs of blank full	Lbs emp.	Net.	Lbs of blank full	Lbs emp.	Net.	Lbs of blank full
2215	720	1495	782	242	540	660	167	493	614
2190	722	1468	798	257	541	644	190	454	630
2184	803	1381	802	272	520	707	109	598	609
2198	702	1496	776	248	528	553	167	386	630
2185	716	1469	790	255	535	562	151	411	563
2202	706	1496	820	266	554	717	149	568	600
2199	911	1282	800	237	563	715	150	565	650
		7087			3781			3475	

Test No. 2

11	12	13	14	15	16	17	
Wt of tank Emp	Net	Pressure gauge Ch. 1	Pres. gauge Ch. 2	Vacuum gauge Ch. 3	Vacuum gauge Ch. 4	Total head.	
61	553	28	27.7	3	2.147	70.47	Total wt. of water pumped 18193-lbs.
68	562	28	27.7	3	2.147	70.47	Speed of pump 1080
65	544	28	27.7	3	2.147	70.47	speed of dyn. 280
58	572	$28\frac{1}{2}$	28.15	3	2.147	71.50	Wgn. reading 68
62	501	$28\frac{1}{2}$	28.15	3	2.147	71.50	Wgn constant.
62	538	$28\frac{1}{2}$	28.15	3	2.147	71.50	W. R. 6 from curve.
68	582	$28\frac{1}{2}$	28.15	3	2.147	71.50	Power given to pump = 3.453 HP
	3852	27.95				71.06	

Test No 2.

Time at start 3 hrs 27 min 0 sec.

" " End 4 " 10 " 30 "

Duration of test 43 min 30 sec.

Work of pump = .8986 HP

efficiency = $\frac{.8986}{3.453} = 26.02\%$

All water was weighed. Four tanks were used.

columns 1 to 12 weights of water.

column 14 pressure gauge connected by table II

column 16 vacuum gauge connected by table IV

column 17 = (col 14 + col 16) times 2.304 plus 1.7 ft.

Speed of pump, of dyn. and dyn. deflection were observed only at beginning of test.

Test No. 3.

April 12 1897

1	2	3	4	5	6	7	8	9	11
Time in sec.	Wt of tank full	Thump	Ht. ft.	Wt. lbs.	Wt. constant	Wt. speed	Pressure gauge	Pres. gauge corrected	Vacuum gauge & corrected
70	2138	642	1496	113	5.85	314	13	11.875	10.46
73	2210	650	1560	115	5.88	314	13	11.875	10.46
75	2150	638	1572	115	5.88	300	12	11.00	10.46
74	2138	633	1505	104	5.78	292	12	11.00	10.46
76	2148	644	1504	112	5.84	314	12	11.00	10.89
Sum 368			7677						

Test No. 3

10	12	13	14	15	16
Vacuum total gauge in ft.	Pump speed	Revs per min.	Power of pump in ft	Power supplied in ft	
11 1/2	53.16	465265	1210	2.046	6.123
11 1/2	53.16	464660	1240	2.065	6.714
11 1/2	57.03	438200	1200	1.871	6.414
11 1/2	57.03	437080	1240	1.887	5.166
12	52.13	4058350 4052150	1240	1.876	6.169
mean.	52.10		1226	1.941	6.117

$$\text{Efficiency} = \frac{\text{col. 15}}{\text{col. 16}} = \frac{1.941}{6.117} = 31.87\%$$

Test. No. 3.

Column 1 gives time required to pump water recorded in column 4. Column 6 was obtained from curve.

Column 9 from table 2, after test no 10 table 3 was used for correcting pressure gauge. Column 11 from table 4

Test No. 4

April 13/1897

Time	Number of sec.	Wt of work full	Wt. emp	Wet	Dyn.	Dyn constant	Dyn Speed	Pressure gauge	Pres. gauge correct
4-41-00	127	2139	643	1516	100	5.77	320	35	31.5
4-43-07									
4-50-00									
4-52-07	127	2137	647	1510	99	5.77	320	35	31.5
4-57-00									
4-59-02	122	2152	710	1442	100	5.77	320	35	31.5
5-4-0									
5-6-11	131	2153	695	1458	99	5.77	320	35	31.5
5-9-0									
5-11-10	130	2174	708	1466	100	5.77	324	35	31.5
5-15-00									
5-17-11	131	2167	694	1473	100	5.77	324	35	31.5
			Sum	8865	mean	5.77			



Test No. 4.

Vacuum gauge	Vacuum gauge corrected.	Total head in ft.	Speed of pump	Revs per min.	Power of pump	Power supplied
5	4.049	83.5	238270 237630	1260	1.812	5.595
5	4.049	83.5	226190 222560	1260	1.805	5.539
5	4.049	83.5	195700 195070	1260	1.794	5.595
5	4.049	83.5			1.690	5.539
5	4.049	83.5			1.712	5.665
5	4.049	83.5	199560 188440	1240	1.707	5.665
		mean		12.60	1.753	5.599

$$\text{Efficiency} = \frac{1.753}{5.599}$$
$$= 31.29\%$$

Test No. 3

April 17, 1897

1	2	3	4	5	6	7	8	9	10
Time	no. of secs.	Ht. full of tank	Temp.	Net.	Dyn.	Dyn. (cont'd)	Dyn. Speed	Pressure gauge	Pres. gauge corrected
11-46-00		2189	688	1501	115		303	20	15.526
11-47-31	91					5.79			
11-52-00		2191	680	1511	115		302	20	15.526
11-53-30	90					5.79			
11-58-00		2189	667	1522	115		310	20	15.526
11-59-31	91					5.79			
12-04-00		2171	665	1506	115		306	20	15.526
12-05-38	98					5.79			
12-06-00		2170	700	1490	115		307	20	15.526
12-07-38	98					5.79			
12-18-00		2177	670	1507	115		305	20	15.526
12-19-44	104					5.79			
12-24-00		2185	691	1494	115		308	20	15.526
12-25-43	103					5.79			
12-29-00		2188	701	1487	115		307	20	15.526
12-30-43	103					5.79			

Test no. 5

Vacuum gauge	Vacuum gauge corrected	Total head, ft.	Pump Speed	revs per min.	Power of Pump	Power Supplied
11	10.029	60.59	116210 115020	1190	1.817	6.144
11	10.029	60.59	111460 110270	1190	1.850	6.094
11	10.029	60.59	103760 102580	1180	1.843	6.255
11	10.029	60.59	95430 94240	1190	1.693	6.174
9 1/2	8.620	57.34	88100 86910	1190	1.564	6.195
9	8.078	56.09	79480 78280	1200	1.478	6.154
9	8.078	56.09	73070 71880	1190	1.480	6.215
9	8.078	56.09			1.473	6.194
	mean	58.49		1190	1.646	6.174

Sum of column 4
11498

sum of column 2 778 sec.

efficiency = $\frac{1.646}{6.174}$
= 26.66%

Test No. 6

April 22 1897.

Time hr. min. sec.	no of sees.	Ht of tank full emp.	Nch.	Rdyn	Rdyn constant	Rdyn Speed	Pressure gauge	Pies. gauge Corrected
3-41-00 43-1	131	2197	683	1512	116	390	336	36.48
3-49-00 51-09	129	2193	653	1538	117	391	340	36.45
3-56-00 58-11	131	2190	681	1509	117	390	341	36.45
4-03-00 05-07	127	2193	697	1496	117	391	340	36.45
4-11-00 13-07	127	2198	674	1524	116	390	339	36.45
4-17-00 19-07	127	2161	697	1464	116	391	340	36.45
	472	Sum	9043					

Test no. 6

Vacuum gauge	Vacuum gauge corrects	Total head	Pump Speed	Revs. per min.	Power of pump	Percent supplied
5 3/4	4.916	97.00	998300	1300	2.036	6.969
6 1/2	5.690	101.06	988380	1300	2.191	7.125
6 1/4	5.529	98.43	977330	1320	2.061	7.145
6 1/2	5.690	101.06	969520	1340	2.077	7.125
6 1/2	5.690	101.06			2.116	7.031
6 1/2	5.690	101.06			2.033	7.053
	mean	99.71		1315	2.086	7.075

$$\text{efficiency} = \frac{2.086}{7.075} =$$

29.48%

April 22 1897

Final

Dynamometer	113
Hyn constant.	5.85~
Hyn. Speed.	3.57
Pressure gauge	47.5~
P. gauge corrected	45.0
Vacuum gauge	1.3~
Vac. gauge corrected	1.07
Total head in ft.	107.81
Pump speed revs per min.	1330
Power supplied	7.15248

efficiency 0

Test no 7

April 24 1897

Time	no of sec.	Ht of tank full	Ht emp	Wt	Dyn	Dyn Constant	Dyn Speed	Pes. gauge	Pes. gauge corrected
1-23-00 24-26	86	2211	654	1360	88	5.81	234	13	6.87
1-31-00 32-26	86	2233	696	1343	84	5.87	253	13	6.87
1-37-00 -38-27	87	2181	687	1494	76	6.00	242	13	6.87
1-43-00 44-30	90	2130	674	1431	69	6.22	232	13	6.87
1-50-00 51-32	92	2160	668	1492	65	6.37	227	13	6.87
1-59-00 2-0-32	92	2135	694	1461	66	6.37	230	13	6.87
2-50-00 6-40	100	2176	686	1491	68	6.37	236	13	6.87
Sum	623			11497					

Test no. 1

Vacuum gauge	Vacuum gauge corrected	Total head	Pump speed	Pers. pump	Power of pump	Power supplied
11	10.029	40.64	883350	1000	1.340	3.935
11	10.029	40.64			1.325	3.780
11	10.029	40.64	871380	920	1.269	3.355
11	10.029	40.64	865810	890	1.195	3.017
11	10.029	40.64	864920	870	1.198	2.848
10 1/2	9.595	39.64	859660		1.144	2.886
10	9.162	38.65	844030	930	1.048	2.961
	mean.	40.27		922	1.217	3.254

Efficiency = $\frac{1.217}{3.254}$
 = 37.4%

Test no. 8

april 24 1887

4. Amly	no of sec.	Wt of bank full	Alt comp	Net	Depr	Dyn constant	Dyn Specs	Pearse gauge	Pers. gauge corrected.
3-35-00									
37-21	141	2144	635	1309	93	5.77	285	20	14.626
3-43-00									
46-21	141	2196	710	1486	92	5.78	283	20	14.626
3-50-00									
52-26	146	2167	682	1485	91	5.79	281	20	14.626
3-56-00									
58-24	144	2146	703	1443	91	5.79	281	20	14.626
4-02-00									
04-28	148	2171	704	1467	91	5.79	282	20	14.626
4-08-30									
11-00	150	2187	698	1459	91	5.79	283	20	14.626
Sum	870			8849					

Test no 8

Vacuum gauge	vac. gauge corrected	Total head	Pump speed.	Revs per min.	Power of Pump	Power supplied
7	6.012	49.26	754340 753440	1100	.9586	4.635
7	6.012	49.26			.9439	4.560
6 3/4	5.857	48.89	740210 739110	1100	.9042	4.487
6 3/4	5.851	48.89			.8908	4.457
6 3/4	5.851	48.89	724540 723430	1090	.8811	4.303
6 3/4	5.851	48.89			.8646	4.319
	mean	49.01	mean	1096	.9012	4.532

$$\text{efficiency} = \frac{.9012}{4.532} = 20.02\%$$

Test no. 9

April 24 1897

Time	No of secs	Atrol water full	Wt. Emp.	Wt.	Dyn	Dyn constant	Dyn Speed	Res. gauge	Res. gauge corrected
4-17-30 20-46	196	2197	649	1530	75-	6.05-	285-	30	25.14
4-25-00 28-11	191	2198	689	1509	75-	6.05-	287	30	25.14
4-33-00 36-11	191	2160	678	1482	74	6.07	287	30	25.14
4-40-00 43-13	193	2209	708	1501	75-	6.05-	286	30	25.14
4-47-00 50-12	192	2206	707	1499	74	6.04	285	30	25.14
4-54-00 57-19	199	2230	690	1540	73.	6.10	285-	30	25.14
Sum	1162			9081					

Test No. 9

Vacuum gauge	Vac. gauge corrected	Total head	Pump Speed	Revs per min.	Power of pump	Power supplied
4 3/4	3.804	68.40	706330 705420	1100	9837	3.919
4 3/4	3.804	68.40			9826	3.937
4 3/4	3.804	68.40	692020 690900	1120	9650	3.906
5	4.049	68.96			9751	3.933
5	4.049	68.96	676370 675230	1120	9789	3.879
5	4.049	68.96			9703	3.846
	mean	68.66		1116	9759	3.903

$$\text{Efficiency} = \frac{.9739}{3.903}$$

$$= 25.01\%$$

Final

April 24 1894

Dynamometer	47
Hyn. constant	5.30
Hyn. Speed	286
Pressure gauge	33.5
Pra. gauge corrected	28.816
Vacuum gauge	1 3/4
Vac. gauge corrected	1.507
Total head in ft.	71.56
Pump speed revs per min	1115
Power supplied	3.159

Efficiency 0

Test no 10 April 26 1897.

Mile	no of sec.	Hk. full	Ht Emp.	Net.	Rdyn	Rdyn constant	Rdyn Speed	Pressure gauge	Rev. gauge corrected.
10-15-00 - 16-48	108	2175	627	1548	53	6.96	235	9	4.555
10-27-00 - 28-50	111	2180	645	1535	51	7.09	220	9	4.555
10-36-00 - 37-50	111	2174	653	1521	50	7.16	224	9	4.555
10-42-00 43-50	111	2165	672	1493	50	7.16	216	9	4.555
11-00-00 01-48	108	2174	692	1482	53	6.96	223	9	4.555
11-06-00 - 07-54	114	2201	678	1523	51	7.09	217	9	4.555
Sum.	663			9102					

Test no. 10

Vacuum gauge	Vac. gauge corrected	Total head in ft.	Pump Speed	Revs per min.	Power of Pump	Power Supply
1 1/2	10.462	36.31			9462	2.627
11	10.029	35.31	6186.83	845	8878	2.411
11	10.029	35.31			8797	2.430
10 3/4	9.825	34.84	603840 604990	850	8520	2.343
11	10.029	35.31	597180 596320	860	8810	2.492
10 3/4	9.825	34.84			8461	2.378
	Mean	35.34		852	8820	2.447

$$\text{Efficiency} = \frac{8821}{2.447} = 36.05\%$$



Test No. 11 April 26 1897.

Time	no. of sec.	ht. of candle fuel	ht. emp.	Wt.	Hg. constant	Hg. spec.	Pres. gauge	Pres. gauge cor. fact.
11-46-0 48-32	152	2168	648	1520	7.02	242	20	15.526
11-52-30 54-58	148	2156	693	1463	7.02	241	20	15.526
11-59-0 12-1-34	154	2201	679	1522	7.02	248	20	15.526
12-6-0 8-29	149	2222	695	1527	7.16	240	20	15.526
sum	603		sum.	6032				

Test. No 11

Vacuum gauge	Vac. gauge corrected.	Total head in ft.	Pump Speed	Revs per min.	Power of Pump	Power supplied
7	6.012	51.33	557250 536330	920	9309	2.739
7	6.012	51.33			9225	2.728
7	6.012	51.33	547480 546340	940	9224	2.799
6 1/2	5.690	50.60			9407	2.771
	mean.	51.13		930	9291	2.759

efficiency = $\frac{9291}{2.759}$

= 33.64%

Test no. 12

April 26 1897

Time	No. of sec.	Ht of tank full	Wt. emp.	Wt.	Hdyn.	Hdyn. constant	Hdyn speed	Res. gauge	Res. gauge corrected
12-57-00 59-31	151	2181	632	1549	83	5.88	293	30	25.1
1-04-00 106-35	153	2167	666	1501	83	5.88	293	30	25.1
1-11-00 1-13-37	157	2177	676	1501	80	5.94	289	30	25.1
1-17-00 1-19-35	155	2187	694	1493	79	6.97	291	30	25.1
1-29-30 1-32-39	157	2208	682	1526	75	6.05	286	30	25.1
1-36-10 -39-42	152	2201	696	1505	68	6.25	283	30	25.1
Sum	929			9075					

Test 10012

Vacuum gauge	Vacuum gauge corrected	Total head in ft.	Pump speed	Revs. per min.	Power of Pump	Power to water supplied
7 1/4	5.520	72.28	497340 496890	1150	1.348	4.344
7	6.012	73.39	481390 480260	1130	1.292	4.344
7 1/2	5.690	72.65			1.263	4.162
7	6.012	73.39			1.286	4.139
6	5.369	71.41	468010 466850	1160	1.249	3.933
5 1/2	4.653	70.26			1.265	3.651
	mean	72.23		1146	1.283	4.098

$$\text{Efficiency} = \frac{1.283}{4.098}$$

$$= 31.31\%$$

Trial.		April 26 1897
Dynamometer.	68	
hlyn. constant.	6.26	
hlyn. speed	296	
Pressure gauge	35-	
Pres. gauge. correctd.	30.429	
Vacuum gauge.	2	
Vac. gauge. correctd.	1.932	
Total head wgt.	74.56	
Pump. speed. revs per min.	1160	Efficiency zero.
Power supplied.	3.818 H	

April 26 1897

Test No. 13

Time.	No of sec.	No of cank full	Mt. emp.	Net.	Hgmn.	Hgmn. constant	Hgmn. start	Pres. gauge	Pres. gauge corrected
4-14-00 16-01	121	2198	631	1567	79	5.96	270	9	4.555
4-20-00 21-37	117	2200	675	1523	79	5.96	271	9	4.555
4-26-30 28-25	115	2194	713	1481	79	5.96	270	9	4.555
4-32-00 33-57	117	2208	708	1570	79	5.96	270	9	4.555
4-37-00 38-45	114	2187	715	1472	78	5.98	271	9	4.555
4-42-30 44-30	120	2202	716	1486	78	5.98	271	9	4.555
Sum.	704			9031					

Test No 13.

Vacuum gauge	Vacuum gauge corrected	Total head in ft	Pump Speed	Revol per min.	Power of Pump	Power supplied
11 1/2	10.462	38.62	428350 427290	1060	9093	3.852
11 1/2	10.462	38.62			9152	3.866
11 1/2	10.462	38.62	415760 414700	1060	9043	3.852
11 1/2	10.462	38.62			9002	3.852
11 1/2	10.462	38.62	404570 403520	1050	9067	3.830
11 1/2	10.462	38.62			8695	3.830
	mean	38.62		1056	9009	3.847

$$\text{Efficiency} = \frac{9009}{3.847} = 23.42\%$$

Test 14

April 26 1897

Time	no of secs	wt of fuel	Alt. emph	Net	Rpm.	Rlym. constant.	Rlym Speed.	Pres. gauge	Pes. gauge corrected
4-48-30 50-40	130	2199	675	1324	74	6.07	274	20	14.625
4-54-00 56-11	131	2212	711	1301	73	6.10	274	20	14.625
4-59-30 5-01-42	132	2208	712	1496	72	6.12	273	20	14.625
5-04-30 5-06-43	133	2204	714	1490	71	6.15	274	20	14.625
5-10-00 5-12-15	135	2209	717	1492	70	6.19	272	20	14.625
5-15-00 -17-18	138	2220	713	1502	70	6.19	271	20	14.625
Sum	799			9010					

Test 14

Vacuum gauge	Vac. gauge reading	Total head in ft.	Pump speed	Revs per min.	Power of Pump	Power supplied
1144	10.242	58.03			1.258	3.729
11	10.029	58.51			1.219	3.697
11	10.029	58.51	280470 279420	1050	1.206	3.645
11	10.029	58.51	274830 273780	1050	1.195	3.626
11	10.029	58.51			1.176	3.572
11	10.029	58.51			1.162	3.558
	mean	58.59		1050	1.203	3.635

Efficiency $\frac{1.203}{3.635} = 33.09\%$

Sept 15 -

April 26 1897

Time	Wt. of fuel	H. of Tank Emp.	Net Wt.	No of Sels.	H. of	H. of const.	H. of Speed	Pres. gauge	Pres. gauge corrected.
5-21-00	2200	675	1525	174	63	6.45	274	25	20
23-54									
5-27-00	2207	723	1484	173	63	6.45	271	25	20
29-53									
5-33-00	2216	723	1493	175	63	6.45	271	25	20
35-53									
5-39-00	2206	727	1479	172	63	6.45	273	25	20
41-52									
5-45-00	2221	727	1494	174	64	6.44	273	25	20
47-54									
		Sum	7475	868					

Sept 13 -

Vacuum gauge	Vac. gauge corrected w. ft.	Total head w. ft.	Pump speed	Revs. p.m.	Power of pump	Power supplied
8	6.994	63.90	35700 355940	1070	1.0183	3.374
8	6.994	63.90			9966	3.362
7 3/4	6.839	63.55	344210 343140	1070	9858	3.385
7 3/4	6.839	63.55			9936	3.349
7 3/4	6.839	63.55	331120 330060	1060	9921	3.405
Mean		63.69		1066	9973	3.375

$$\text{efficiency} = \frac{9973}{3.375} = 29.53\%$$

Final.

April 26 1897.

Dynamometer.	54
dyn. constant.	6.90
dyn. speed.	272
Pressure gauge	31
Pres. gauge corrected	26.306
Vacuum gauge	2 1/4
Vac. gauge corrected.	1.986
Total head in ft.	66.189
Pump speed, revs.	1060
Power supplied	3.071 HP

Efficiency zero.

1	2	3	4	5	6	7	8
Summary							
No of test	Total head in ft.	Pump speed	efficiency in %	Gallons per min	Powr supplied	vel. in feet per sec.	HP in outflow water
1	35.68	723	30.9	44.66	1.247	4.552	.0036
2	71.06	1080	26.02	50.16	3.453	5.112	.0051
3	52.10	1226	31.87	148.15	6.117	15.10	.1313
4	83.5	1260	31.29	83.05	5.399	8.486	.0231
5	58.49	1190	26.66	106.34	6.174	10.84	.0486
6	99.71	1315	29.48	84.28	7.075	5.498	.0099
Final	107.81	1330	0	0	7.152	0	0
7	40.27	922	37.4	124.06	3.264	8.092	.0316
8	49.01	1096	20.02	73.18	4.532	7.459	.0016
9	68.66	1116	25.01	56.22	3.903	5.730	.0072
Final	71.56	1115	0	0	3.159	0	0
10	35.34	852	36.05	98.76	2.447	10.65	.0389
11	51.15	930	33.67	71.98	2.759	7.337	.0151
12	72.23	1146	31.31	70.29	4.098	7.164	.0140
Final	74.56	1160	0	0	3.818	0	0
13	30.62	1056	23.42	92.30	3.847	9.408	.0318
14	58.59	1050	33.09	81.14	3.635	8.270	.0216
15	63.67	1066	29.55	92.31	3.375	9.409	.0318
Final	66.189	1060	0	0	3.071	0	0

The summary gives the results of all the different tests.

Columns 2 to 6 inclusive are taken from the corresponding columns of the tests.

Column 7 is the velocity in feet per second of the water flowing from the discharge pipe. It is equal to the quantity of water in cubic feet divided by the area of the pipe in square feet.

Column 8 is the kinetic energy of the water at outflow. It is equal to the square of the velocity multiplied by the number of pounds of water discharged per second divided by twice the value of gravity and by 550 foot pounds to change it to

horse-power. This shows that very little of the energy lost in the pump remains in the water.

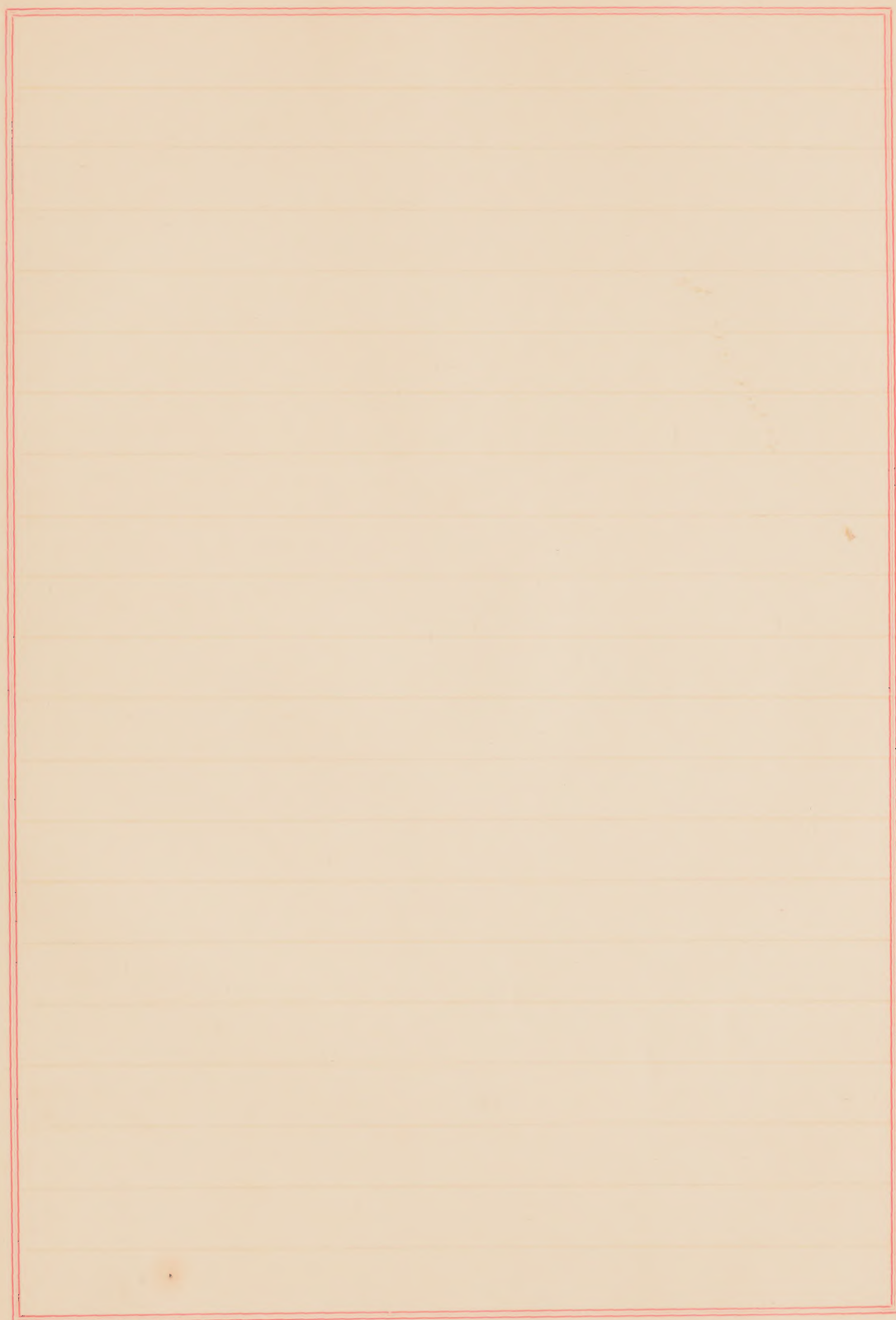
The pump is rated by the maker to give 150 gallons per minute. The nearest approach to this was in test 3 where 148.15 gallons were obtained at a head of 52.10 feet. The efficiency was then 31.87% at a pump speed of 1226. In test 7 the discharge was only 24 gallons less at a head of 48.27 feet. The efficiency was here a maximum, reaching 37.4% while the pump speed was only 922. In test 4 the pump speed is 34 greater than in 3, the efficiency is about the same but the quantity has fallen to $\frac{5}{9}$ of the latter. This shows that the

quantity is not exactly proportional to the speed alone but also depends upon the head.

Neither does the efficiency follow any definite law, for an examination of the summary shows that it is independent, in its variations, of the total head, speed or discharge.

The best general recommendations that can be given are that the pump be run at a speed of from 850 to 1050 revolutions per minute and under a head of from 35 to 60 feet.

C. F. Cludius
H. Cabot.



3 1198 03071 0995



N/1198/03071/0995X

3 1198 03071 0995



N/1198/03071/0995X

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